Appendix A

Liquid Hydrogen Target Update

The design of the target for this experiment, as described in the proposal, is predicated on several novel ideas which were to be tested for the first time with the Qweak target. The Qweak target, we argued in the proposal, is really the prototype for the Moller target. Although the Qweak target is still being commissioned and many of the key results are only just now coming to light, it is appropriate in this update to review what has been learned so far in order to see whether those Qweak ideas and design aspects crucial to the Moller LH2 target hold any water.

The most crucial aspect of the Moller target design which needs to be validated is the novel use of computational fluid dynamics (CFD) as a design tool. Computational fluid dynamics was used in almost all aspects of the design of the Qweak target. It was used to tailor the cell design in order to optimize the flow, temperature and density profiles across the beam axis in the hydrogen volume as well as at the cell windows. These simulations were used to fix the mass flow required of the target, one of the most crucial design parameters. The pressure head represented by the complicated cell shape was derived by CFD. Analytic calculations for the Qweak target's heater and some aspects of the heat exchanger were checked with CFD simulations. CFD simulations fixed the raster size required for the target and helped us design strategies for various off-normal events. In many respects the novel design which emerged was considered a bit of a gamble, given that CFD was not a proven tool for target design.

The 35 cm long, high power Qweak target has met its ambitious design goals, at least to the extent we have been able to measure them until now. The target has been successfully operated with 3 kW of cooling power, many times greater than any target previously built. It has been run routinely now with 150 μA of 1.165 GeV electrons. The target boiling contribution to the asymmetry widths in the experiment is too small to measure until now, although an upper limit of 100 ppm has been derived for the boiling contribution with indications it may be considerably smaller than this still. The bulk density changes have also been bounded to less than 0.2% at 150 μA. This should be compared to the performance of the standard pivot

15 cm machined cells, for which the density variation at 100 μA has been measured to be 20%, a factor of 500 worse. Although the design raster size for the Qweak target was 4x4 mm^2, the target's performance is so good that it is operated routinely at 150 μA with a raster size of only 3x3 mm^2.

The fact that the Qweak target has achieved all of its design goals validates the use of CFD as a design tool. We note that the matrix of 24 solid targets that are also part of the Qweak experiment were also designed with CFD. The relationship between temperatures at the center of each target to thermometry scattered around the solid target frame was studied with CFD. Knowing how high these thermometers can safely go, by virtue of the CFD calculations, has made it possible to put more beam current on our solid targets than has ever been done before at JLab.

It also shows that the heat exchanger design process used for Qweak was correct. Note that the Qweak heat exchanger is a completely novel design which combines a 4 K and a 15 K heat exchanger using overlapping heat exchanger coils in the same shell.

It also shows that the high power heater design and fabrication process was correct. The 3 kW heater performance is unmatched. When beam trips occur, or beam is restored to full current, the typical temperature excursions in the target loop thermometers are less than 0.1 K.

The pressure head predicted for the Qweak target at the design mass flow of 1.1 kg/s was 1.2 psi. The head measured with the Qweak target at this massflow is 1.1 psi, in amazingly good agreement with the prediction considering how very difficult it is to calculate this ahead of time. Note that head and massflow are the two most crucial design parameters for most of the target's components.

The fact that the required massflow and pressure head were achieved for the Qweak target also validates the pump design. Problems have been encountered with the Qweak pump bearings, which have led to some down time. However the basic deliverables of the pump (head and massflow) have been achieved at the required values.

Qweak initiated the use of faster helicity reversal as a tool to mitigate the effects of target noise on the experiment. Fast Fourier transforms acquired under a wide varity of conditions during the Qweak experiment's commissioning phase show that this is an important and effective tool for reaching the goals of the experiment, and its effectiveness for the Moller experiment is now also validated.

Qweak also pioneered the use of a recovery heat exchanger at the ESR in order to boost the effectiveness of the ESR by making use of the enthalpy of the returning 4 K coolant. The ESR recovery heat exchanger (designed by Rao Ganni) has proven to be enormously successful. It has boosted the 15K cooling power the ESR can deliver by about 50%.

Another novel design feature now validated by Qweak is the re-configuration of the existing transfer line infrastructure in order to simultaneously supply both 4 K coolant and 15 K coolant to the target, and in particular, to return both coolant sources on separate lines back to the ESR. This required using the LN2 supply shield as a 20 K helium return. A small superconducting polarimeter magnet in the Qweak experiment is also fed and successfully operated with this highly unusual configuration.

A director's review of JLab cryogenic capacity has been held. The final report is available at

`http://www.jlab.org/div_dept/dir_off/ccr/.`

The Moller experiment's 5 kW cooling power requirement figures prominently in the report. The report states that the planned ESR #2 by itself has the 5 kW capcaity required for the Moller experiment. The ESR #2 building is currently under construction, and the refrigerator has been designed (but not yet funded). However, the first of the director's review committee's recommendations is that funding be secured for ESR #2 on a timeline that makes it available for the Moller experiment, as early as 2015. Finally, the report also recommends (on page 5) that the Hall A 4K transfer lines be re-evaluated and upgraded for the 12 GeV era in part because they have unusually high heat loads associated with them, and in part to better meet the demands of the 12 GeV era (such as the Moller experiment).

To summarize: the Qweak target employed a large number of novel and highly unusual ideas to meet its goals. We now know that every single one of these new ideas has worked. This greatly reduces the risk associated with the extensions needed for the Moller target. The cooling power needed for the experiment has been carefully considered by the lab and solutions are already under way that will insure the experiment's requirements can be met.